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Stratigraphic Cross Sections of the Lewis Shale in the Eastern Part of the Southwestern Wyoming Province, Wyoming and Colorado

By Jane S. Hearon

Pamphlet to accompany

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Contents

Figures

[Figures are on map sheet]

Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)

Datum

Horizontal coordinate information is referenced to the North American Datum of 1927.

The datum for cross sections is informally known as the Asquith marker.

Depth in wells on cross sections is measured depth below the surface.

Abbreviations

API	American Petroleum Institute
FS	flooding surface
ft	feet
GR	gamma ray
RES	resistivity
USGS	U.S. Geological Survey

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Abstract

Three stratigraphic cross sections *A–A′*, *B–B′*, and *C–C′* were created for the Lewis Shale and associated strata in the eastern part of the Southwestern Wyoming Province of Wyoming and Colorado. The cross sections highlight 15 clinothems within the Lewis Shale, Fox Hills Sandstone, and Lance Formation progradational system (also referred to as the Lewis Shale system). Additionally, the cross sections indicate that multiple source areas were active at the same time during deposition of the Lewis Shale. Specifically, the north-to-southeast cross section *A–A′* demonstrates that the northern, sand-rich source was being deposited and onlapping onto an older, southern, mud-rich source.

Introduction

The Maastrichtian Lewis Shale comprises nearshore- to deep-marine sandstone, siltstone, and mudstone, and is located in the eastern part of the Southwestern Wyoming Province (also referred to as the Greater Green River Basin) in southern Wyoming and northwestern Colorado (fig. 1 on map sheet). Regionally, the Lewis produces abundant natural gas and lesser amounts of oil from low porosity, low permeability clastic reservoirs. The Lewis interfingers with the marginal marine Fox Hills Sandstone, which in turn, interfingers with the coastal plain Lance Formation, and represents time-equivalent, genetically related, marine strata.

The Lewis Shale has been extensively studied over the last half-century due to the prolific amounts of natural gas it has produced in the Southwestern Wyoming Province. The province formed during the Laramide Orogeny and was subdivided into several subbasins by intrabasin uplift (Roehler, 1992). Specifically, the Lewis has produced gas from the Great Divide, Washakie, and Sand Wash Basins, and associated Wamsutter arch and Cherokee ridge (fig. 1). As of 2022, the Lewis has produced approximately 1.5 trillion cubic feet of gas and 22.4 million barrels of oil (IHS Markit, 2022). Numerous studies suggest that the Lewis and related strata are contained in an overpressured, basin-centered gas system, that is self-sourced and produces from very tight (<0.1 millidarcies) clastic reservoirs (see Law, 2002, and references therein). Additionally, several stratigraphic cross sections, of various vintages, have shown that the Lewis Shale system represents a series of prograding clinothems deposited in shelf, slope, and basin-floor environments (for example, see figs. 3.4 and 3.8 in Pasternack, 2007; Carvajal and Steele, 2009). The cross sections and associated data release (Hearon, 2023) presented in this report build upon the previous research of the Lewis Shale and highlight the complex stratigraphy of the Lewis Shale-Fox Hills Sandstone-Lance Formation system. The cross sections emphasize that there were at least three sediment sources active during Lewis deposition, and they illustrate how flooding surfaces can be correlated over long distances between the different sediment input areas.

Data and Methods

Cross sections *A–A′* (north to southeast, fig. 2 on map sheet), *B–B′* (west to east, fig. 3 on map sheet), and *C–C′* (southwest to northeast, fig. 4 on map sheet) were created using gamma-ray (GR) and resistivity (RES) logs from 105 wells throughout the eastern part of the Southwestern Wyoming Province. The cross sections transect a broad area underlain by the Lewis Shale, which is bounded to the north and south by fault zones, to the east by uplift, and to the west by the Lewis stratigraphic pinch-out. Cross section *A–A′* comprises 48 wells, cross section *B–B′* comprises 25 wells, and cross section *C–C′* comprises 36 wells. Wells 19*, 26*, 69*, and 70* are intersection points between the three cross sections and their locations are shown on the map in figure 1. The interpreted cross sections are shown both with and without wells logs for enhanced visualization of the system's geometry (figs. 2–4).

Tops for the Almond Formation of Mesaverde Group (hereafter, Almond Formation), Lewis Shale, and Fox Hills Sandstone were interpreted across the three cross sections (figs. 2–4). Additionally, 15 flooding surfaces (numbered 1–15 in figs. 2–4) were correlated from the log data and were used to define the tops of 15 clinothems. The flooding surfaces were identified where the GR intensity was relatively high and often wrapped around the log display, and where the RES was relatively low. Resistivity logs are not displayed on the cross sections due to space constraints.

All well logs are from the Colorado Oil and Gas Conservation Commission and Wyoming Oil and Gas Conservation Commission websites (Colorado Oil and Gas Conservation Commission, 2022; Wyoming Oil and Gas Conservation Commission, 2022). Logs that were not available in a digital format were digitized from a raster image. Well header information and depths to key stratigraphic surfaces are listed in the associated data release (Hearon, 2023).

Paleogeography and Stratigraphy

The Lewis Shale and related strata were deposited in a shallow marine embayment along the western shoreline of the Western Interior Seaway (Roehler, 1993) prior to the formation of the subbasins and uplifts within the eastern Southwestern Wyoming Province shown in figure 1. The oldest stratigraphic unit in the cross sections is the Upper Cretaceous Almond Formation, which is the uppermost formation of the Mesaverde Group. The Almond Formation is a mix of shallow marine and nonmarine coastal sediments. It consists primarily of sandstones, mudstones, and coal beds, and records the overall landward migration of the coastline during relative sea-level rise. In general, when compared to the Lewis Shale, the Almond has lower GR values, higher RES values, and a highly serrated signature in both sets of logs (GR logs shown in figs. 2–4). There is an abrupt and distinct change in log character at the top of the Almond and the base of the overlying Lewis, marking a notable change from sandstone and coal to mudstone. At this contact, the GR intensity and RES in the Lewis shift to much higher and lower values, respectively, and the range in values for both logs is much narrower. Additionally, the contact between the Almond and Lewis shows stratigraphic rise to the north (fig. 2, cross section *A–A′*) and to the west (fig. 3, cross section *B–B′*) toward the Rock Springs uplift (fig. 1), recording the last major sea-level transgression in the area (McMillen and Winn, 1991).

The Lewis Shale conformably overlies the Almond Formation and is subdivided into three members, in ascending order (figs. 2–4): (1) an informal lower member; (2) a middle, formally named Dad Sandstone Member; and (3) an informal upper member (Gill and others, 1970; Pyles and Slatt, 2000). The lower member of the Lewis is predominantly mudstone and has consistently higher GR values when compared to the rest of the Lewis. The lower member is interpreted as a third-order transgressive systems tract and may be an internal source of gas for sandstone accumulations within the Lewis (McMillen and Winn, 1991; Pyles and Slatt, 2000; Pasternack, 2007).

The top of the lower member is marked by the highest GR zone in the interval and is informally referred to as the Asquith marker (figs. 2–4; Pasternack, 2005, after Asquith, 1970). The Asquith marker is an organic-rich black shale that can be correlated in well logs throughout the study area and is the datum for all three cross sections. The Asquith marker is interpreted as a third-order condensed section that represents the maximum flooding surface of the Lewis Shale and records the turn-around from transgression to regression of the Cretaceous Western Interior Seaway (McMillen and Winn, 1991; Pyles and Slatt, 2000). The Asquith marker has been studied extensively in the Champlin 276 Amoco D-1 well (API number 4900720477), which cored the entire interval. Pyrolysis data indicate that the Asquith marker has an average total-organic-carbon content of 3.1 percent and is composed of mixed Type II/III kerogen (Pyles, 2000; Rigoris, 2005). The top and bottom of the Asquith marker can be mapped throughout the eastern part of the province, and flooding surface 1 merges with and downlaps onto the top of the Asquith marker as illustrated in wells 17, 53, and 93 (figs. 2–4). The Lewis Shale is often modeled as a self-sourced petroleum system (Law, 2002), where the organic-rich Asquith marker is a source for oil- and gas-charged sandstone reservoirs.

The Dad Sandstone Member of the Lewis Shale overlies the lower member and is markedly sand rich. Sandstone intervals within the Dad Member are interpreted as deltaic, slope, and basin floor channels and fan deposits resulting from turbidity currents and other sediment gravity flows (Hettinger and Roberts, 2005, and references therein). In logs, the sandstones of the Dad Sandstone Member frequently have a low-GR, blocky signature, and are interbedded with thin, high-GR flooding surfaces that often define the tops of each individual clinothem. The locus of sand deposition in the Dad Sandstone Member is in the eastern part of the Washakie Basin (fig. 2, well 31), where it is nearly 1,400 feet (ft) thick. The sandy intervals of the Dad Sandstone Member are the primary gas reservoirs in the Lewis.

The upper member of the Lewis Shale is dominated by siltstone and mudstone, but also contains some isolated, shoreface sandstone reservoirs. The upper member interfingers with the overlying Fox Hills Sandstone on a regional scale.

The uppermost stratigraphic units shown in the cross sections are the Fox Hills Sandstone and Lance Formation, which were deposited in shallow marine and coastal plain environments, respectively. The Fox Hills and Lance are time-correlative with the Lewis and represent the proximal, landward equivalents to the offshore marine Lewis. In the GR logs (figs. 2–4), the Fox Hills often has a distinct coarsening-upward signature, which is common in prograding shelfal environments, while the Lance shows a thinly bedded, serrated signature, often interbedded with coal. The complex interfingering of these formations is indicative of the multiple high-order regressions and transgressions of the Western Interior Seaway.

Flooding Surfaces, Clinothems, and Shelf Edges

Each of the 15 flooding surfaces interpreted in the cross sections (figs. 2–4) display a clinoform geometry, and each successive flooding surface bounds and defines 15 distinct clinothems. From wells 1 to 40, section *A–A′* (fig. 2) is approximately dip-parallel to a series of prograding clinothems that were deposited from mostly north-to-south across the area that is presently divided into the Great Divide Basin, Wamsutter arch, and Washakie Basin. The clinothems have a characteristic sigmoidal shape and illustrate the transition from the sandy shelf to the muddy slope to the sandy basin floor. The shelfal topsets are primarily contained within the Lance Formation and Fox Hills Sandstone, while the slope foresets and basin-floor bottomsets are within the Lewis Shale.

From wells 40 to 48, cross section *A–A′* (fig. 2) turns to the southeast and is approximately dip parallel to a second and separate set of prograding clinothems that were likely deposited from southeast-to-northwest across the eastern margins of the area that is presently divided into the Sand Wash Basin and Cherokee ridge. The 15 flooding surfaces can be directly correlated from the separate northern and southeastern prograding systems. Sediment from the northern clinothems onlaps onto the edges of the southern clinothems beginning around well 40. Additionally, flooding surfaces 8 to 15 converge at wells 47 and 48.

Cross section *B–B′* (fig. 3) is mainly strike-parallel to the north-south clinothems in cross section *A–A′* and the cross section highlights the locus of sand deposition of clinothem 5. The basin-floor fan package within clinothem 5 is nearly 400-ft thick in the center (wells 57–63) and characteristically thins from its central axis to its western and eastern margins.

Cross section *C–C′* (fig. 4) is mostly oblique to the north-south clinothems of cross section *A–A′* (fig. 2) and is also slightly oblique to a third set of clinothems that prograded from southwest to northeast. Here, only the oldest flooding surfaces (1–4) defined in *A–A′* can be correlated to the sediment source in the southwest. The younger flooding surfaces converge toward the south where they cannot be distinguished from one another. The transition from the southwestern clinothem system to the distal edges of the northern clinothem system occurs between wells 86 and 87 (fig. 4). Weimer (1970), Winn and others (1985), and Roehler (1990, 1993) postulated a second, southwest source area for the Lewis Shale, but they did not have enough well control in the area to properly illustrate this idea.

Shelf edges (1–15) were identified for the 15 clinothems interpreted in cross section *A–A′*. The edges were chosen where the clinoform geometry display a morphological break in slope, and where the coarsening-upward sand packages of the Fox Hills Sandstone typically grade into mudstone of the Lewis Shale. There is a shift in clinothem trajectory between shelf edge 6 and 7. In clinothems 1 to 6, the shelf edges have an aggradational/progradational stacking pattern, whereas clinothems 7 to 15, are strongly progradational. This stacking pattern has been demonstrated by McMillen and Winn (1991), Carvajal and Steel (2009), and Olariu and others (2012), and is interpreted to reflect changes in sediment supply relative to sea-level and local subsidence.

Discussion

The three cross sections *A–A′*, *B–B′*, and *C–C′* record deposition of the Lewis Shale-Fox Hills Sandstone-Lance Formation system as it prograded and infilled an embayment in the Western Interior Seaway during the Maastrichtian. The stratigraphy of this system has been extensively studied in the past; however, these cross sections illustrate, for the first time, three different sediment input directions that were active at the same time. The main sediment source was from the northern margins of the embayment, whereas the southeast and southwest sources contributed far less sediment into the study area. It is likely that additional sediment accumulation from the two southern sources occurred outside of the present-day study area but has been removed by post-depositional uplift and erosion.

Hamzah (2002) details onlap of the Lewis Shale onto a paleo-high, similar to what is displayed in cross section *A–A′*, however, the author never discusses this beyond its occurrence. Here, I interpret the onlap of the northerly source onto a high created by the distal edges of a second set of clinothems likely sourced from the southeast (wells 40–48). It is apparent that the southeastern source either shuts off at various times during basin infill, or more likely is depositing sediment outside of the current study area. Specifically, the northern source is depositing sediment the entire time between flooding surfaces 1 to 15, however, the southeastern source appears to deposit sediment in the area only between flooding surfaces 1–2, 3–5, 6–7, and after 15. Additionally, GR logs from wells 40–48 indicate that deposition in this southern area was dominated by mudstone and siltstone as opposed to the sandier accumulations from the north.

Summary

Overall, deposition of the Lewis Shale system records both the transgression (lower member and Asquith marker) and regression (Dad Sandstone Member and upper member) of the Cretaceous Western Interior Seaway during the Maastrichtian in Wyoming and Colorado. Flooding surfaces identified in well logs (figs. 2–4) can be correlated over long distances and provide evidence that multiple source areas were active at the same time. Progradation of the Lewis Shale system into the paleobasin resulted in deposition of nearly 1,400 feet of cumulative sandstone beds, which are now productive gas reservoirs.

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References Cited

Asquith, D.O., 1970, Depositional topography and major marine environments, Late Cretaceous, Wyoming: American Association of Petroleum Geologists Bulletin, v. 54, no. 7, p. 1184–1224. [Also available at https://doi.org/10.1306/5D25CBB3-16C1-11D7-8645000102C1865D.]

Carvajal, C.R., and Steel, R.J., 2009, Shelf-edge architecture and bypass of sand to deep water—Influence of shelf-edge processes, sea level, and sediment supply: Journal of Sedimentary Research, v. 79, no. 9, p. 652–672. [Also available at https://doi.org/10.2110/jsr.2009.074.]

Colorado Oil and Gas Conservation Commission, 2022, OGCC historical well plat search: Colorado Oil and Gas Conservation Commission database, accessed 2022, at https://cogcc.state.co.us/#/home. [Database also available at https://ecmc.state.co.us/weblink/.]

Gill, J.R., Merewether, F.A., and Cobban, W.A., 1970, Stratigraphy and nomenclature of some Upper Cretaceous and lower Tertiary rocks in south-central Wyoming: U.S. Geological Survey Professional Paper 667, 53 p. [Also available at https://doi.org/10.3133/pp667.]

Green, G.N., 1992, The digital geologic map of Colorado in ARC/INFO format: U.S. Geological Survey Open-File Report 92–0507–D–O, 1 sheet, scale 1:500,000. [Also available at https://doi.org/10.3133/ofr92507DO.]

Green, G.N., and Drouillard, P.H., 1994, The digital geologic map of Wyoming in ARC/INFO format: U.S. Geological Survey Open-File Report 94–425, 1 sheet, scale 1:500,000, 10-p. pamphlet. [Also available at https://doi.org/10.3133/ofr94425.]

Hearon, J.S., 2023, Formation tops data from the stratigraphic cross sections of the Lewis Shale in the eastern part of the Southwestern Wyoming Province, Wyoming and Colorado: U.S. Geological Survey data release, https://doi.org/10.5066/P9XRPCSC.

Hamzah, S.N.M., 2002, Subsurface correlations of the Lewis Shale in the Washakie and Great Divide Basins, Wyoming: Golden, Colo., Colorado School of Mines, M.S. thesis, 144 p.

Hettinger, R.D., and Roberts, L.N.R., 2005, Lewis Total Petroleum System of the Southwestern Wyoming Province, Wyoming, Colorado, and Utah, chap. 9, *in* U.S. Geological Survey Southwestern Wyoming Province Assessment Team, comps., Petroleum systems and geologic assessment of oil and gas in the Southwestern Wyoming Province, Wyoming, Colorado, and Utah: U.S. Geological Survey Digital Data Series DDS–69–D, ver. 1.0, 39 p., 1 CD-ROM. [Also available at https://doi.org/10.3133/ds69D.]

IHS Markit, 2022, US well history and production database: Englewood, CO, IHS Markit, accessed February 2022, at http://www.ihsenergy.com. [Available from IHS Markit, 15 Inverness Way East, Englewood, CO 80112.]

Law, B.E., 2002, Basin-centered gas systems: American Association of Petroleum Geologists Bulletin, v. 86, no. 11, p. 1891–1919. [Also available at https://doi.org/10.1306/61EEDDB4-173E-11D7-8645000102C1865D.]

McMillen, K.J., and Winn, R.D., Jr., 1991, Seismic facies of shelf, slope, and submarine fan environments of the Lewis Shale, Upper Cretaceous, Wyoming, *in* Weimer, P., and Link, M.H., eds., Frontiers in sedimentary geology—Seismic facies and sedimentary processes of submarine fans and turbidite systems: Springer-Verlag, New York, p. 273–287.

Olariu, M.I., Carvajal, C., Olariu, C., and Steel, R.J., 2012, Deltaic process and architectural evolution during cross-shelf transits, Maastrichtian Fox Hills Formation, Washakie Basin, Wyoming: American Association of Petroleum Geologists Bulletin, v. 96, no. 10, p. 1931–1956. [Also available at https://doi.org/10.1306/03261211119.]

Pasternack, I., 2005, The Weimer marker bentonite—A regionally persistent correlation horizon within the Upper Cretaceous Lewis Shale, eastern greater Green River Basin, Wyoming and Colorado: The Mountain Geologist, v. 42, no., 2, p. 67–83. [Also available at https://archives.datapages.com/data/rmag/mg/2005/pasternack.htm.]

Pasternack, I., 2007, The Lewis Shale petroleum system, eastern Greater Green River Basin, Wyoming and Colorado: Golden, Colo., Colorado School of Mines, Ph.D. dissertation, 590 p.

Pyles, D.R., 2000, A high-frequency sequence stratigraphic framework for the Lewis Shale and Fox Hills Sandstone, Great Divide and Washakie Basins, Wyoming: Golden, Colo., Colorado School of Mines, M.S. thesis, 261 p.

Pyles, D.R., and Slatt, R.M., 2000, A high-frequency sequence stratigraphic framework for shallow through deep-water deposits of the Lewis Shale and Fox Hills Sandstone, Great Divide and Washakie Basins, Wyoming, *in* Weimer, P., ed., Deep-water reservoirs of the world [electronic resource]: Gulf Coast Section Society of Economic Paleontologists and Mineralogists Foundation, 20th annual Bob F. Perkins Research Conference, Houston, Tex., Dec. 3–6, 2000, Houston, Tex., p. 836–861. [Also available at https://doi.org/10.5724/gcs.00.15.0836.]

Rigoris, A., 2005, Source-rock analysis of the lower member of the Lewis Shale, Washakie Basin, Wyoming: Golden, Colo., Colorado School of Mines, M.S. thesis, 120 p.

Roehler, H.W., 1990, Stratigraphy of the Mesaverde Group in the central and eastern greater Green River Basin, Wyoming, Colorado, and Utah: U.S. Geological Survey Professional Paper 1508, 52 p., 2 pls. [Also available at https://doi.org/10.3133/pp1508.]

Roehler, H.W., 1992, Introduction to Greater Green River Basin geology, physiography, and history of investigations: U.S. Geological Survey Professional Paper 1506–A, 14 p., 1 pl. [Also available at https://doi.org/10.3133/pp1506A.]

Roehler, H.W., 1993, Stratigraphy of the Upper Cretaceous Fox Hills Sandstone and adjacent parts of the Lewis Shale and Lance Formation, east flank of the Rock Springs uplift, southwest Wyoming: U.S. Geological Survey Professional Paper 1532, 57 p., 5 pls. [Also available at https://doi.org/10.3133/pp1532.]

Weimer, R.J., 1970, Rates of deltaic sedimentation and intra-basin deformation, Upper Cretaceous of Rocky Mountain region, *in* Morgan, J.P., ed., Deltaic sedimentation, modern and ancient: Society of Economic Paleontologists and Mineralogists Special Publication no. 15, p. 270–292. [Also available at https://doi.org/10.2110/pec.70.11.]

Winn, R.D., Jr., Bishop, M.G., and Gardner, P.S., 1985, Lewis Shale, south-central Wyoming—Shelf, delta front, and turbidite sedimentation, *in* Nelson, G.E., ed., The Cretaceous geology of Wyoming: Wyoming Geological Association 36th annual field conference guidebook, p. 113–130. [Also available at https://archives.datapages.com/data/wga/data/043/043001/113_wga0430113.htm.]

Wyoming Oil and Gas Conservation Commission, 2022, WOGCC data—Production system: Wyoming Oil and Gas Conservation Commission [WOGCC] database, accessed 2022, at https://wogcc.wyo.gov.

For more information about this report, contact
Director, Central Energy Resources Science Center
U.S. Geological Survey
Box 25046, Mail Stop 939,
Denver, CO 80225
For additional information, visit https://www.usgs.gov/centers/central-energy-resources-science-center
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